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X-Ray Stress Analysis

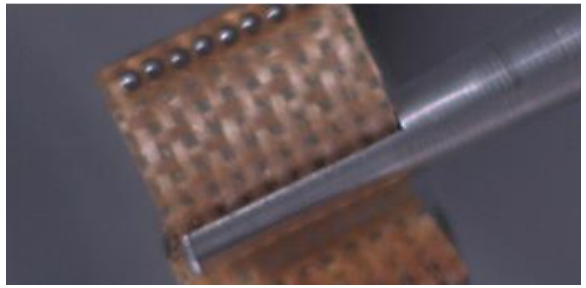
using the Pulstec µ-X360s

PROCESS MANAGEMENT

Process Technology

Machine Technology

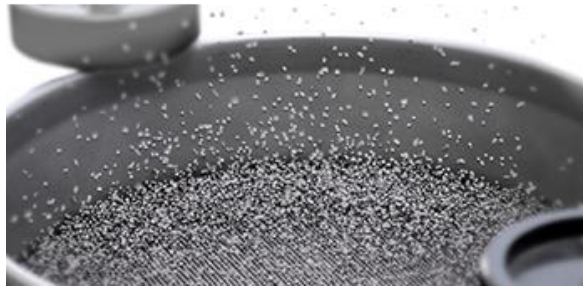
Special Processes



Process Development

QUALITY MANAGEMENT

Quality Assurance



Supplies

Services

Training

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Agenda

PART 1 cos-alpha method

PART 2 Pulstec μ-X360s

PART 3 Measurement Automation

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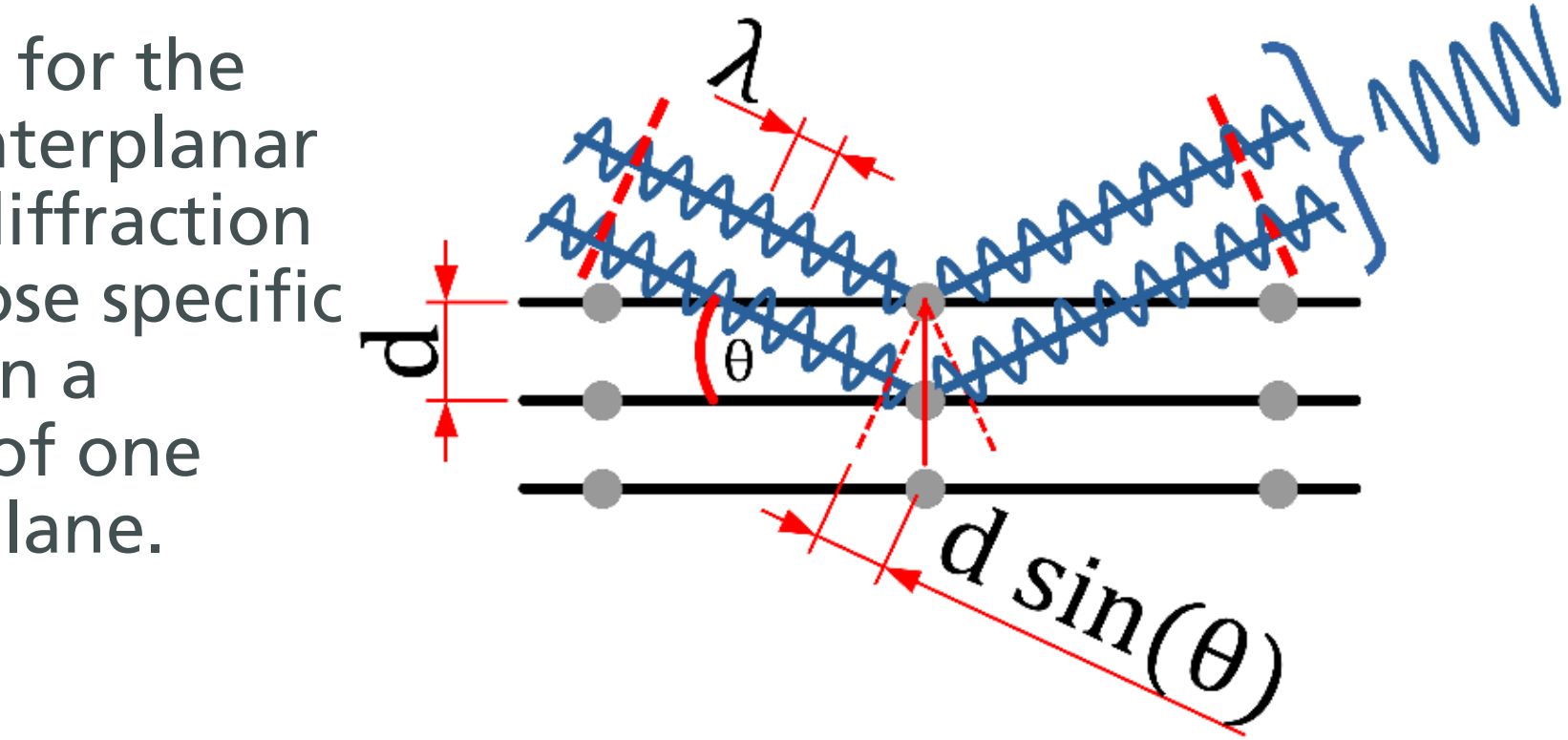
PART 1 cos-alpha Method

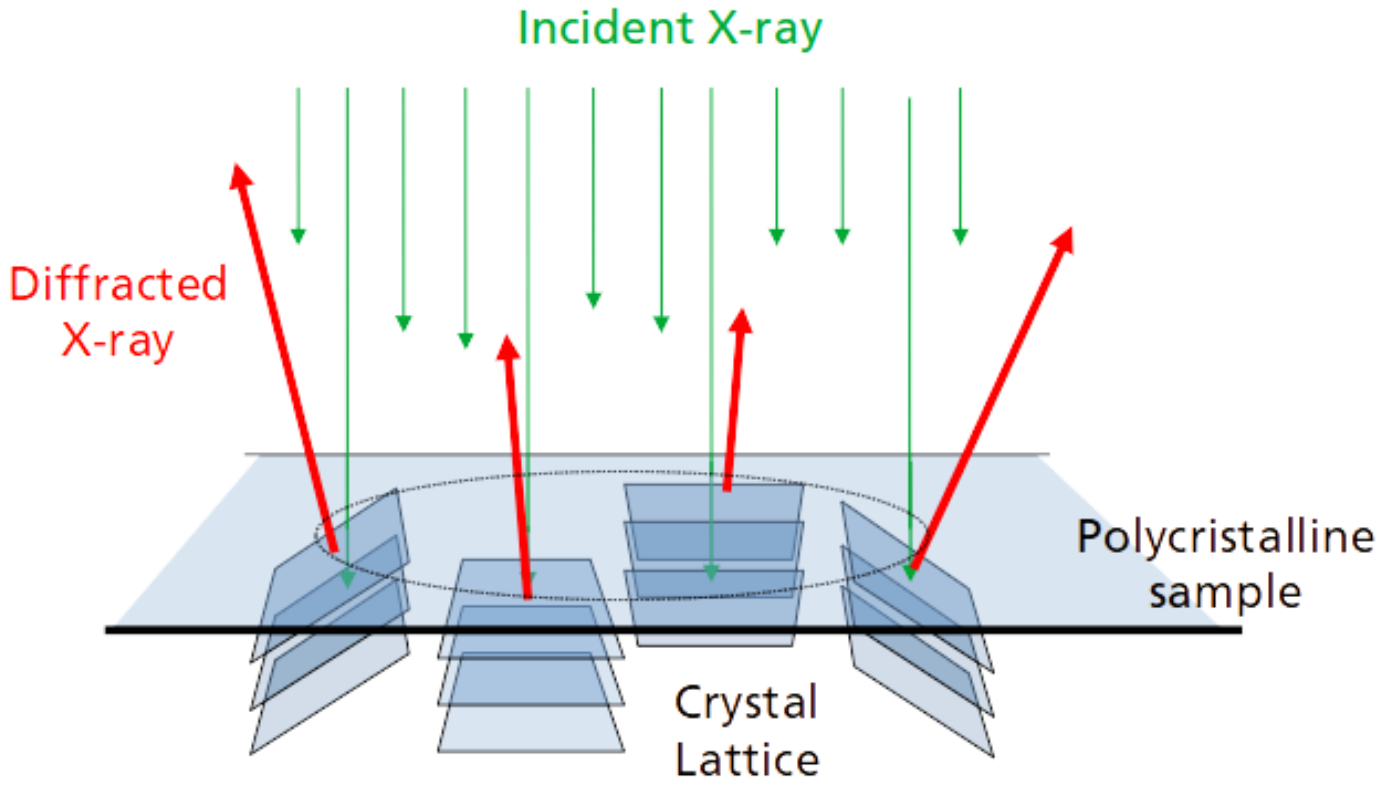
Bragg's Law

At a given wavelength λ for the crystal lattice with the interplanar spacing d there will be diffraction of only those X-rays whose specific incident angle θ results in a specific path difference of one wavelength per lattice plane.



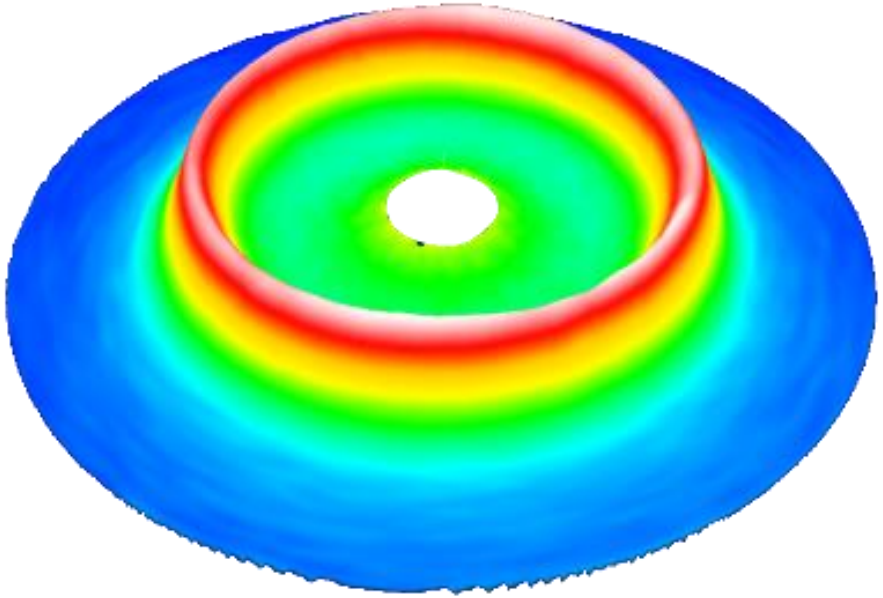
X-Ray diffraction on polycristalline materials

At a fixed direction of the incident X-ray, the diffracted beams originate from those crystal orientations that fulfill Bragg's law. The diffracted beams form a cone around the axis of the incident X-ray.



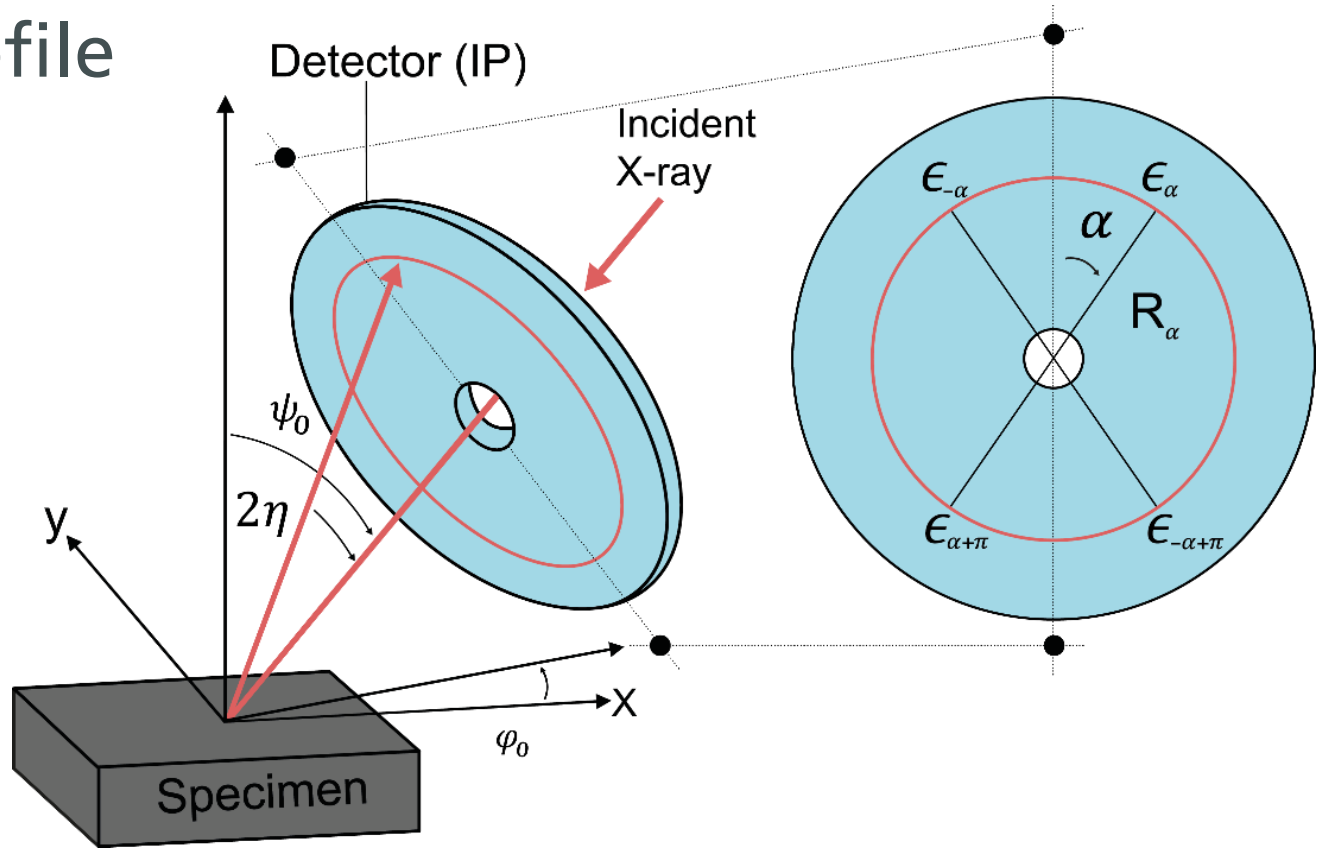
Debye-Scherrer ring

The diffraction cone coming from the specimen surface forms a Debye-Scherrer ring on a two-dimensional detector.

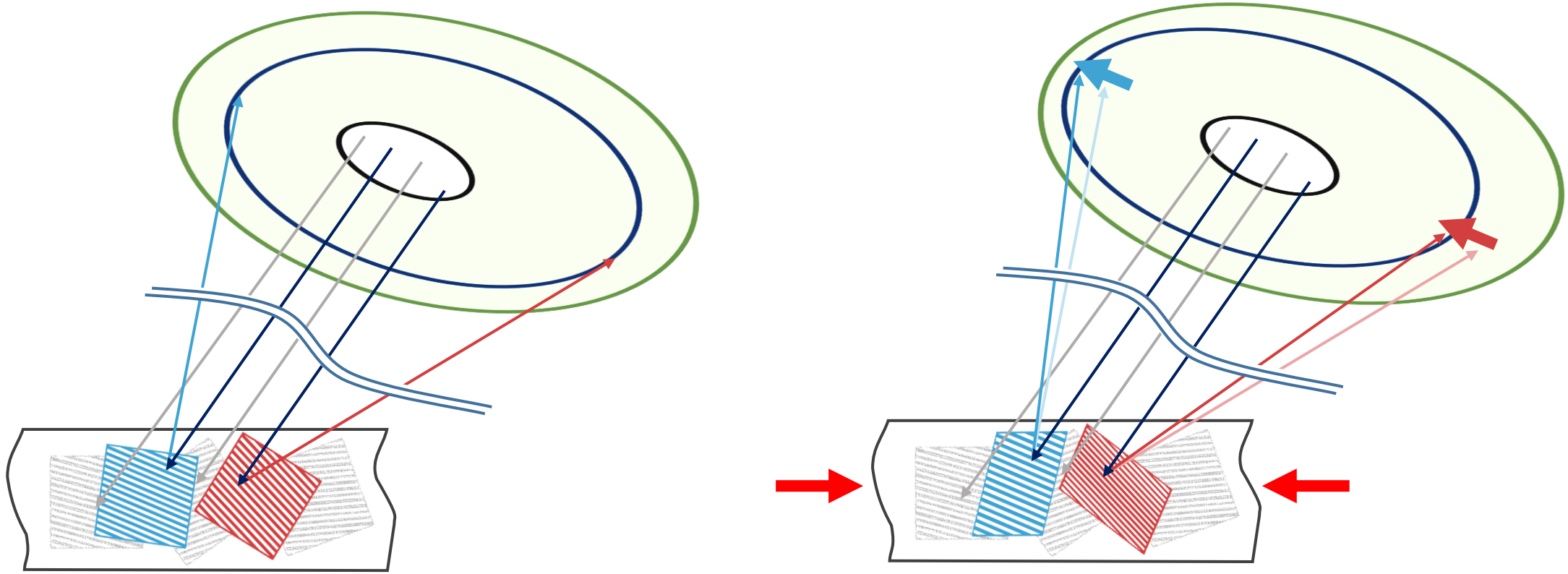


The cos-alpha setup

Instead of a single diffraction profile the cos-alpha method utilizes the complete Debye-Scherrer ring information. Therefor only one incident direction is needed to calculate a plane stress condition from the Debye-Scherrer ring shift.



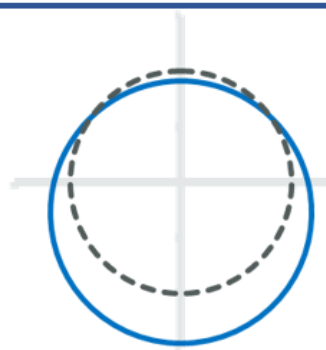
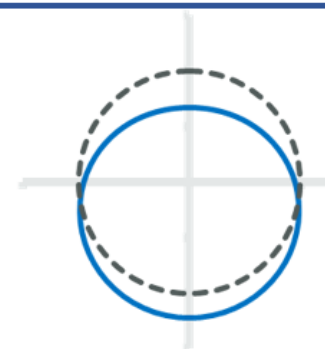
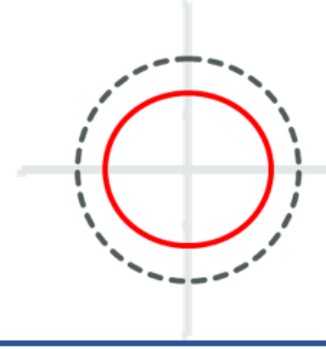
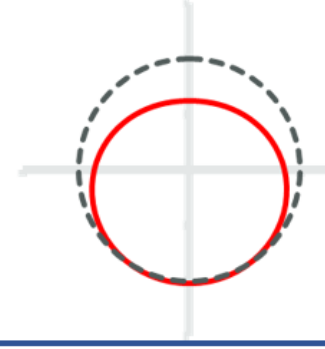
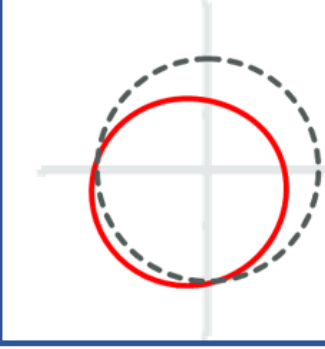
Debye-Scherrer ring shift



Blue Lattice Plane
The lattice plane is aligned more parallel to the surface. The grid spacing is increased by the compressive stress in the direction of measurement.
Green Lattice Plane
The lattice plane is aligned more vertical to the surface. The grid spacing is decreased by the compressive stress in the direction of measurement.

Debye-Scherrer ring shift

Depending on the stress introduced to the specimen the Debye-Scherrer ring will shift and deform. The table gioives an overview on the influence of different stress tensors on the DSR.

	$\boldsymbol{\sigma_x} = \mathbf{200\ MPa}$ $\sigma_y = 0\ MPa$ $\tau_{xy} = 0\ MPa$	$\sigma_x = 200\ MPa$ $\boldsymbol{\sigma_y} = \mathbf{150\ MPa}$ $\tau_{xy} = 0\ MPa$	$\sigma_x = 200\ MPa$ $\sigma_y = 150\ MPa$ $\boldsymbol{\tau_{xy}} = \mathbf{100\ MPa}$
DSR $\varphi_0 = 0°$			
DSR $\varphi_0 = 90°$			

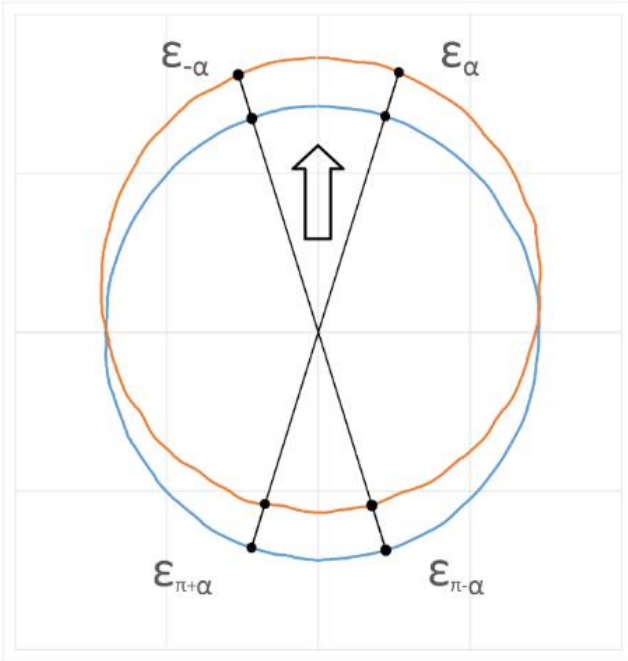
Stress Calculation by DSR shift

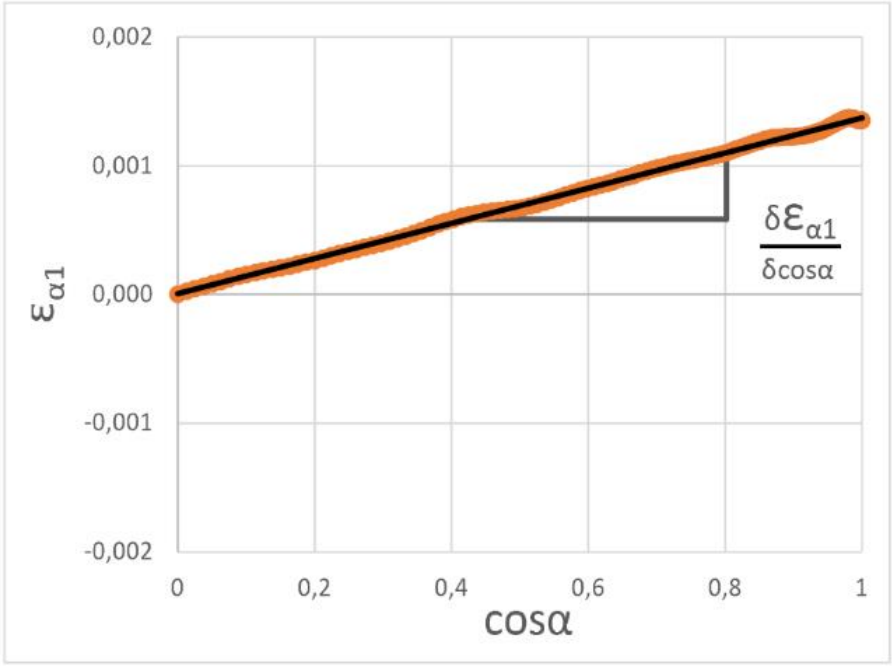
The ring shift

$$a_1 \equiv \frac{1}{2}\{(\varepsilon_\alpha - \varepsilon_{\pi+\alpha}) + (\varepsilon_{-\alpha} - \varepsilon_{\pi-\alpha})\}$$

plotted over cos(alpha) gives the stress currently in the specimen by the equation.

$$\sigma_x = -\underbrace{\frac{E}{1+\nu}\frac{1}{\sin 2\eta \sin 2\psi_0}}_{\text{Elastic constant}}\underbrace{\left[\frac{\partial a_1}{\partial \cos\alpha}\right]}_{\text{Slope}}$$





Out-of plane shear stresses

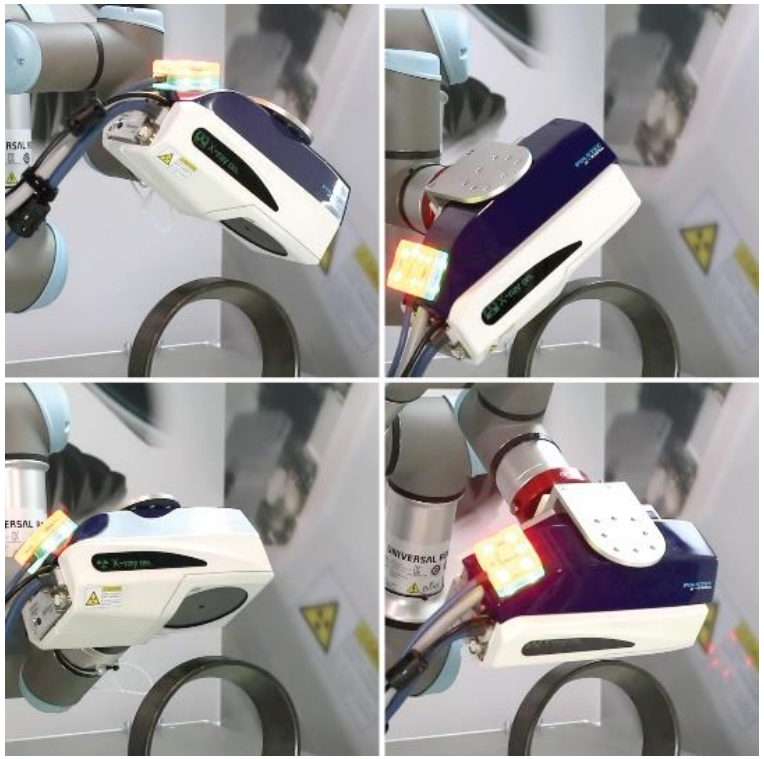
The aformentioned forumla is only valid for plane stress conditions. This becomes clear by looking at the complete equation for the individual strains:

$$\epsilon_{\alpha 1} = -\frac{1+\nu}{E}\left[\left(\sigma_x - \sigma_z\right) sin\ 2\psi_0 + 2\tau_{zx}\ cos\ 2\psi_0\right] sin\ 2\eta\ cos\ \alpha$$

While σ_z can be assumed to be zero this is not always true for the out-of plane stress τ_{zx}. In this case a second measurement direction is needed to calculate the stress tensor components.

Stress Tensor calculation

To calculate the complete stress tensor without σ_z four measurement directions are recommended. This can be done by tiliting the sensor unit in different directions or turning the device or sample.



Comparison to sin²psi

- Instead of several incident angles cos-alpha uses different α-angles this leads to:
  - Generally shorter measurement times since no movement is necessary during the measurment
  - Insensitivity to distance and angle misalignment

- The Complete Debye-Scherrer ring is captured this gives additional information on texture and grain size.

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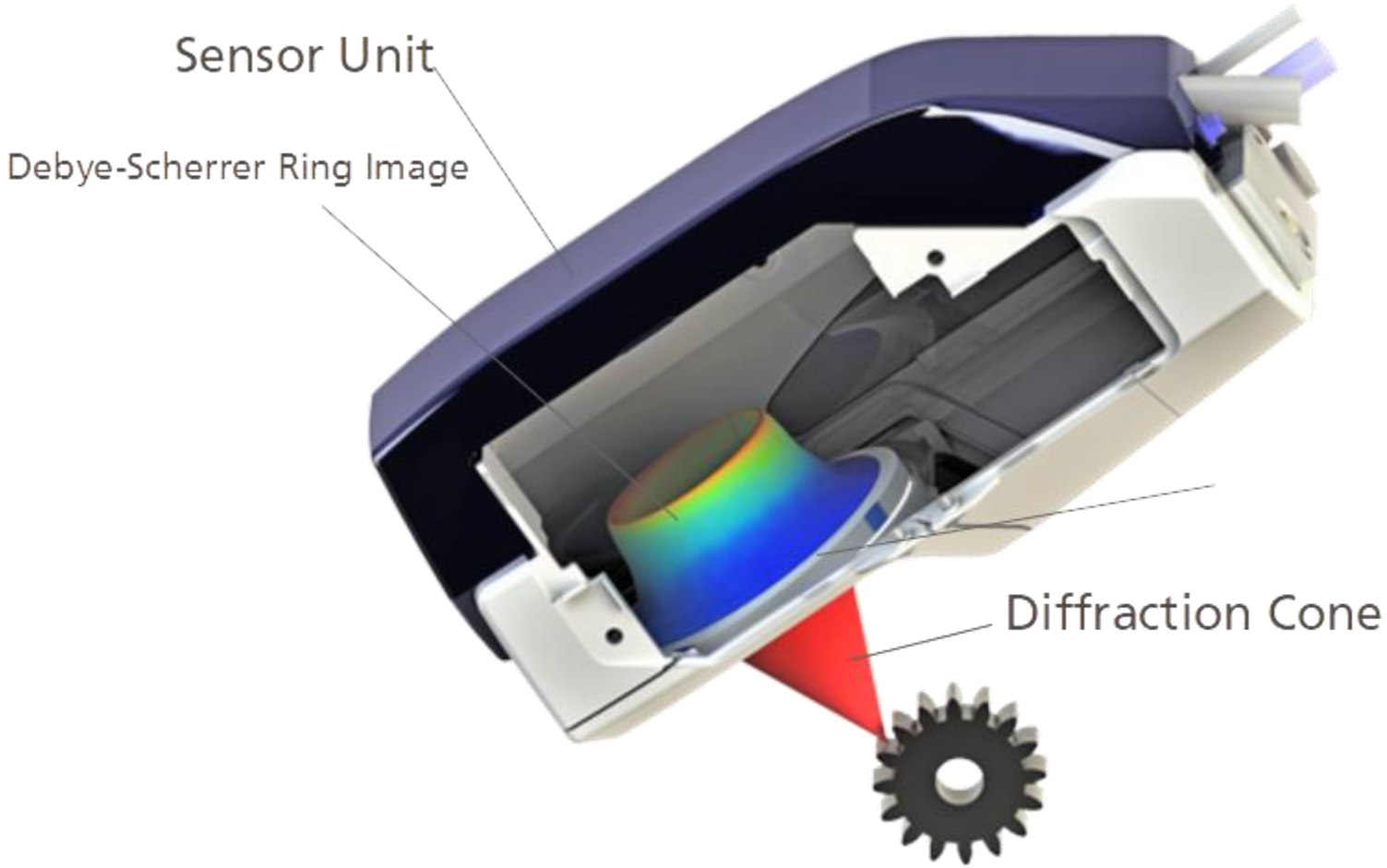
PART 2 Pulstec µ-X360s

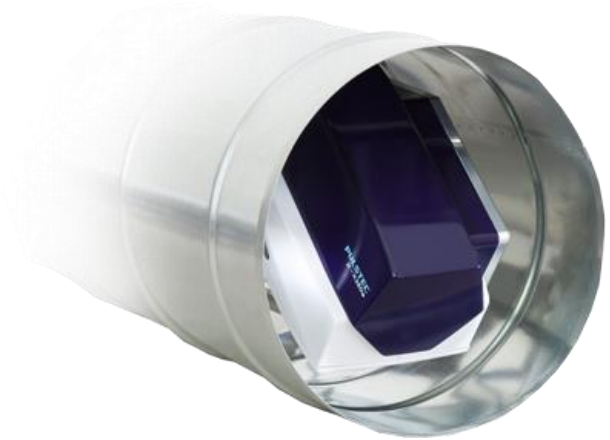
Specification

Power supply:	230 V(AC) @130 W
Dimensions:	
Sensor Unit [mm]:	L213 x W114 x H107
Power Supply [mm]:	L289 x W235 x H159
Weight:	
Sensor Unit:	2,4 kg
Power Supply:	6,2 kg

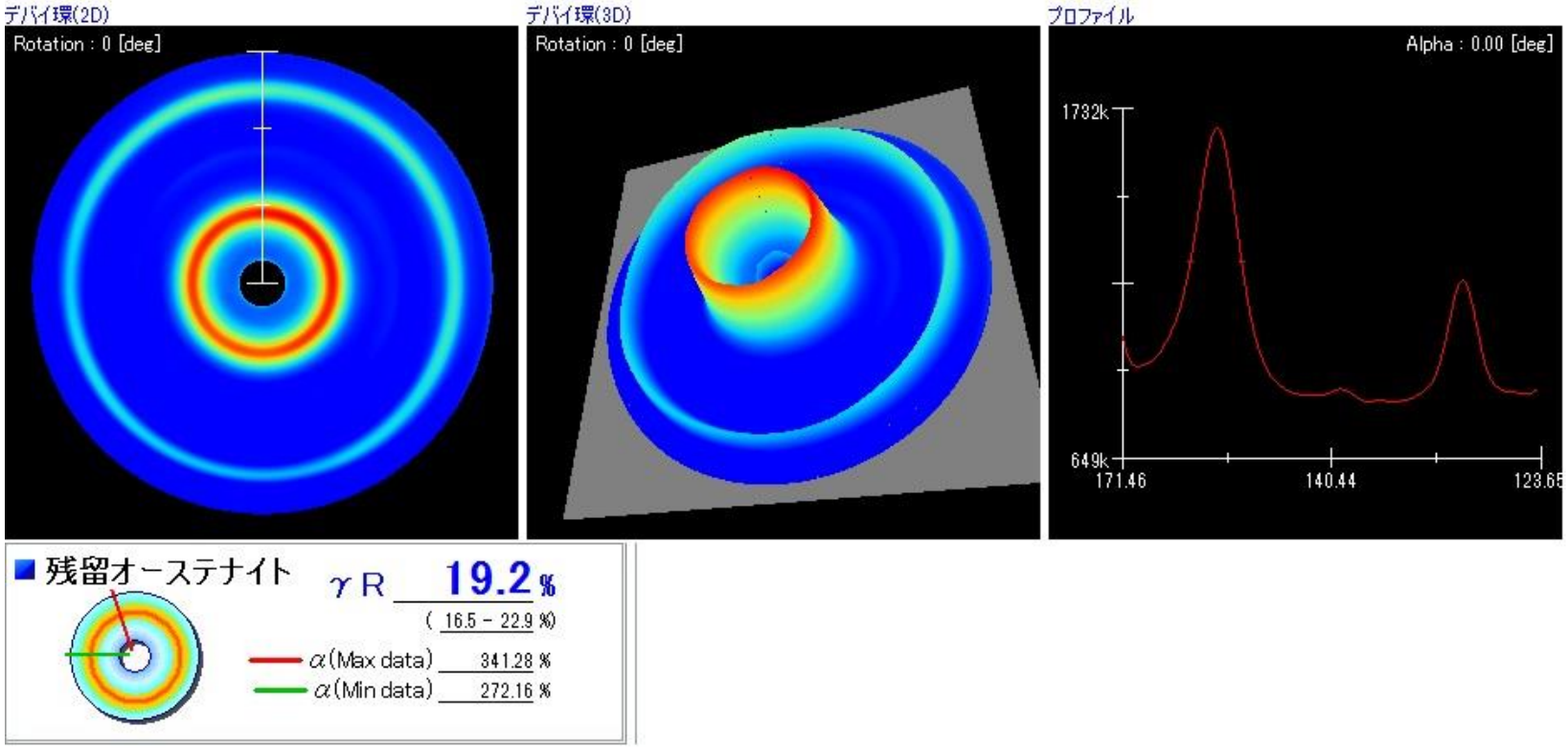

Sensor Unit
Debye-Scherrer Ring Image
Diffraction Cone

Radiation protection

Due to the low power needed to gather measurement information the radiation dose is indistinguishable from background radiation in a distance of approx. 1 meter. Operation without safety shielding is therefor possible.

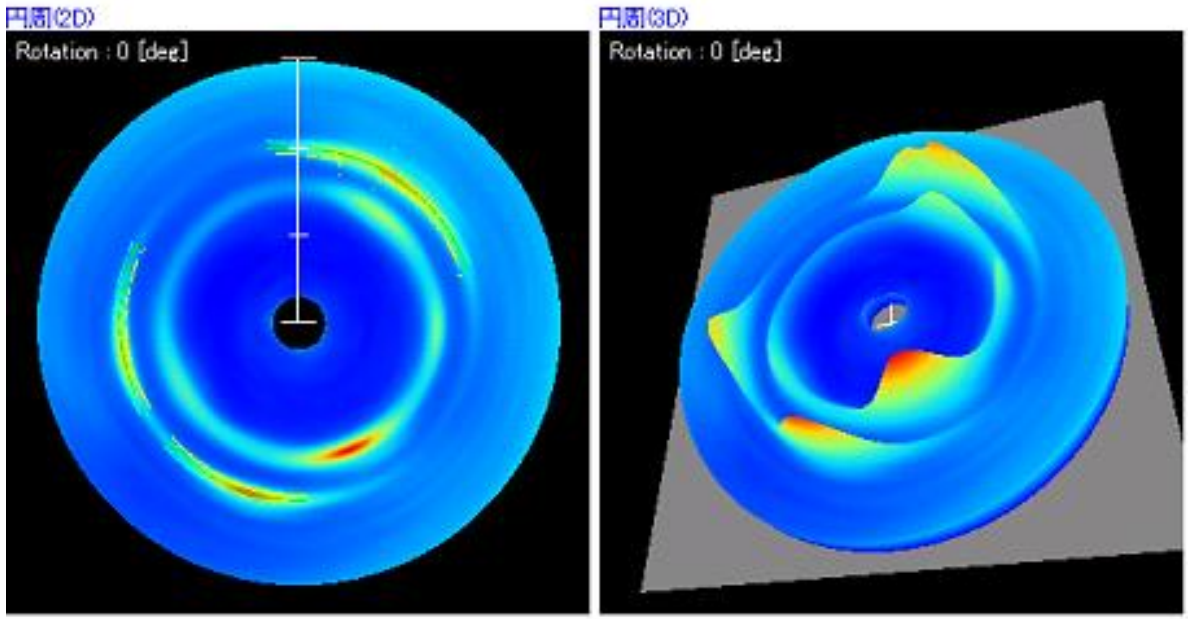


Retained Austenite Measurement

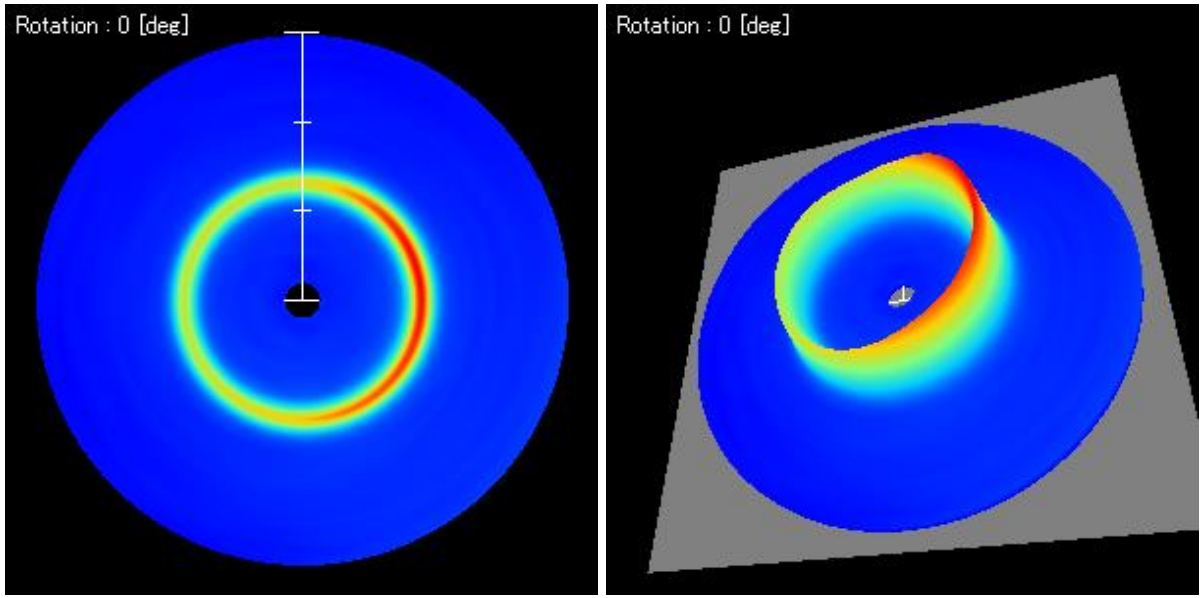


Additional Information from the Debye-Scherrer ring

Grain size

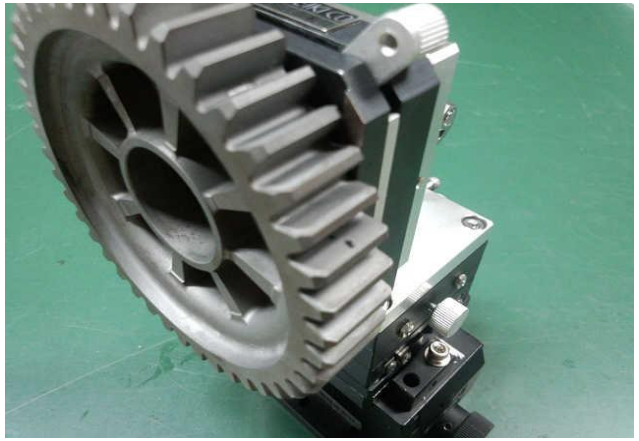


Grain orientation (texture)

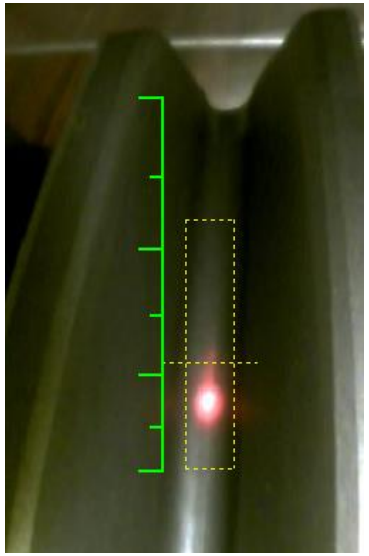


Sectional Analysis of the Debye-Scherrer ring

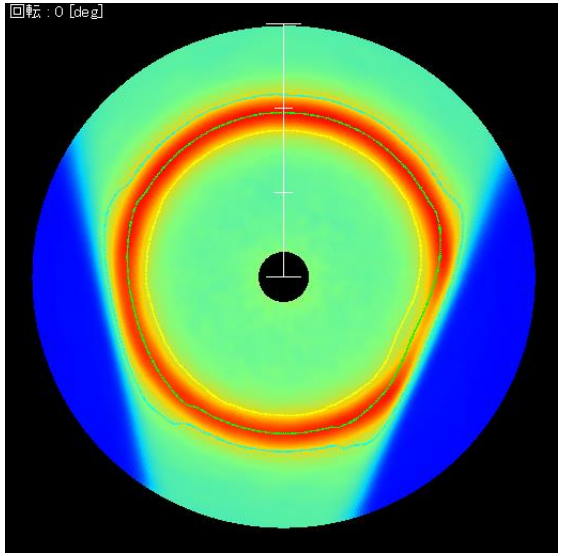
Instead of analysing the complete Debye-Scherrer ring it is also possible to excluded certain areas that have been shaded by the specimen or fixture.



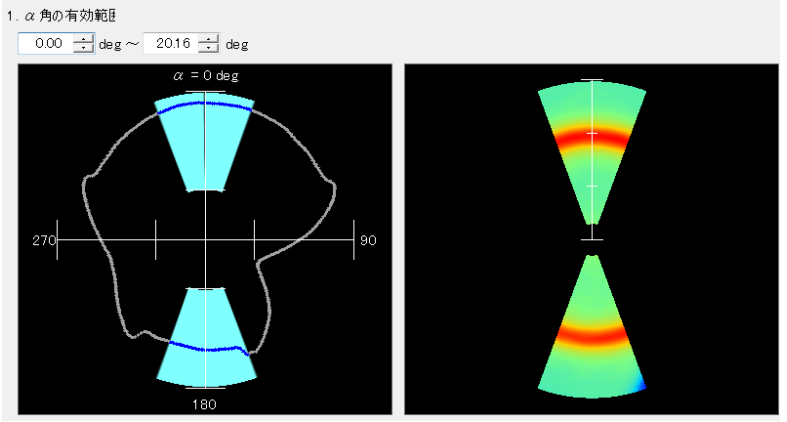
Specimen



Setup



Measurement Result



Selection of Analyzed Area

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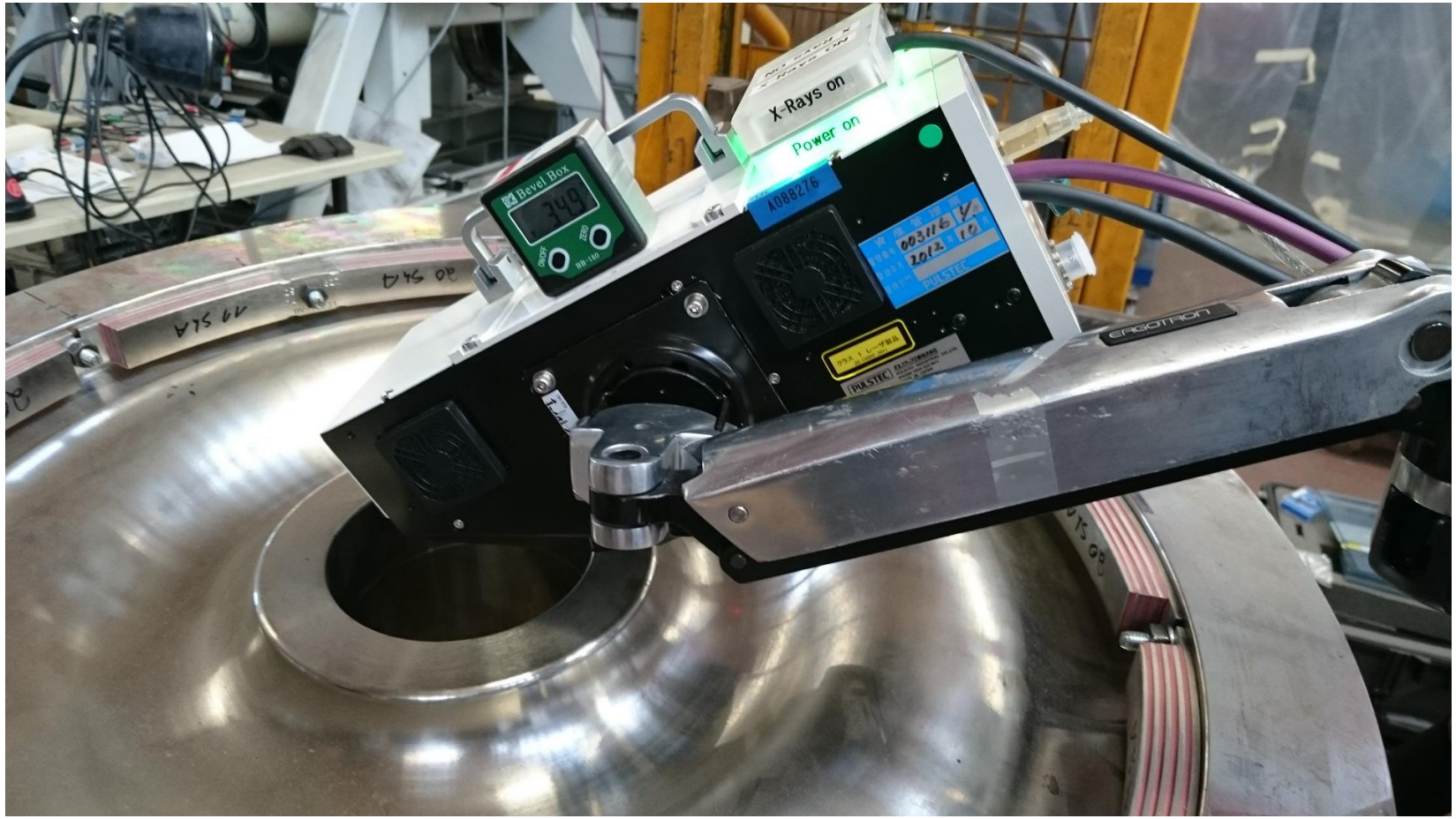
Application Examples

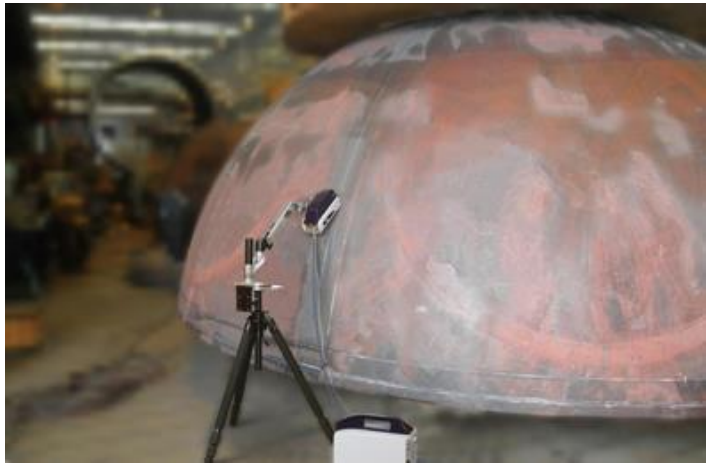
Application Examples

Railway Wheels



Application Example

Welds and
huge strcutres



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PART 3 Measurement Automation

Measurement Automation

Easy Setup via Robot control

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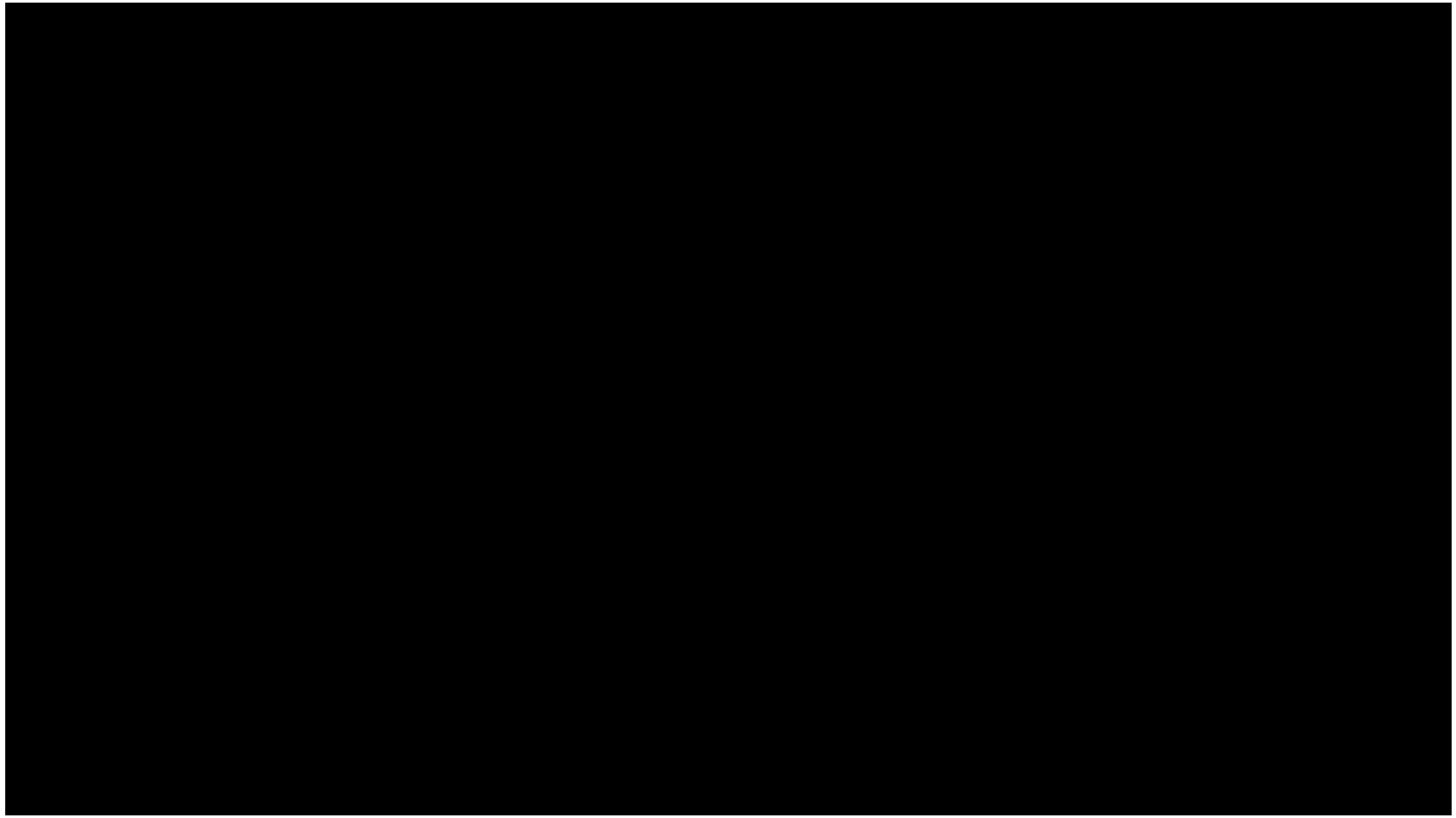
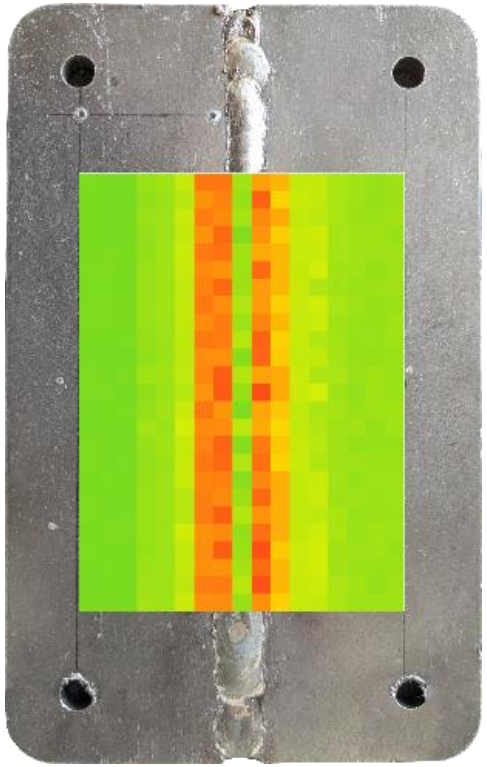
PART 3 Measurement Automation StressEasy

StressEasy

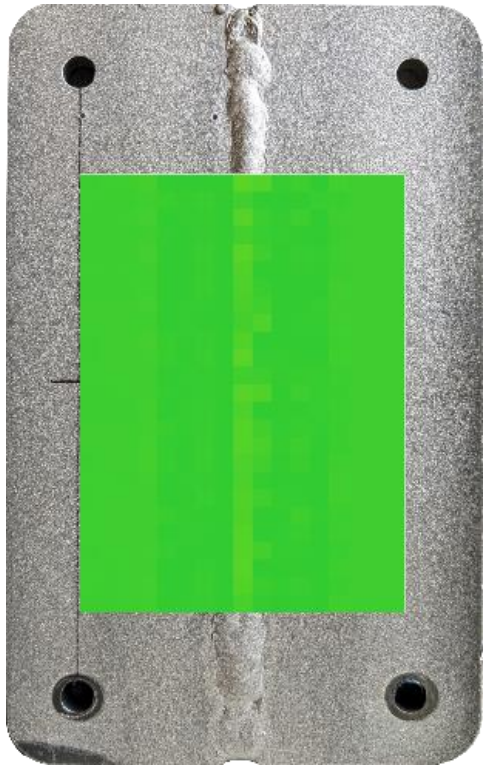
https://vimeo.com/559910333



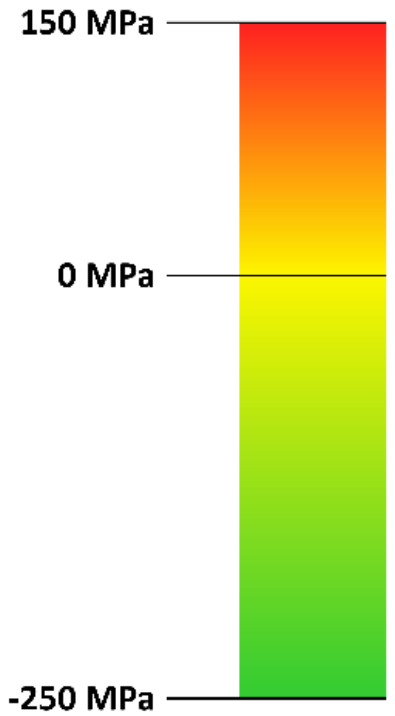
Stress Mapping



As welded



Shot Peened



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